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THE EFFECTS OF MATERIAL PROPERTIES ON MATERIALS HANDLING PROCESSES

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Wisconsin University

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The Effects of Material Properties on Materials Handling Processes

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B. C. Mehta, D. Patel, R. W. Heins, R. W. Christensen

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In order to better understand the fundamental aspects of a belt conveyor materials handling system, a model system with closed circulation has been constructed. The evaluation and the measure of its performance based on various factors of the system has been made using a statistical experimental design approach.

Numerous problems were encountered, particularly at the material transfer points in the system. These problems and their solutions are detailed in this report.

Based on several tests, it was observed that the type of material being conveyed had a significant effect. On the other hand, the equipment variables proved to be relatively insignificant for the range of variables considered.

During this investigation, several conveyor belt simulator designs were considered and one of these was built. The results of tests on the simulator were in general agreement with the model conveyor test results. Based on limited results, the conveyor belt simulator appears to offer considerable potential for investigating the response of a conveyor belt system.

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Conveyor simulation						
Conveyor systems						
Statistical experimental design						
Material properties						
Rapid excavation						
Model conveyor						

FINAL TECHNICAL REPORT

OCTOBER 1973

THE EFFECT OF MATERIAL PROPERTIES ON MATERIALS HANDLING PROCESSES

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PREFACE

This report covers the final six months accomplishments on Contract No. H0220042 in the research program entitled, "The Effect of Material Properties on Materials Handling Processes," R. W. Heins, Principal Investigator.

SUMMARY

This is the final report on Contract No. H0220042 under which a closed circulation belt conveyor materials handling system has been constructed and tested. Also, an initial working model conveyor belt simulator was constructed and limited tests were run.

Numerous problems were encountered, particularly at the material transfered points in the system. Several designs were fabricated and tested before a workable system was developed. This required changes in the slope and direction of the chutes, the addition of pneumatic vibrators and the use of baffles to control the velocity of flow of the material.

A series of 16 tests and a series of 8 tests, respectively, were performed with the model conveyor system. It was observed that the type of material had a significant effect. On the other hand, equipment variables proved to be relatively insignificant for the range of variables considered.

The results of the conveyor belt simulator tests were in general agreement with the model conveyor test results. Based on the limited results presented here, it would appear that a conveyor belt simulator offers considerable potential for investigating the response for a conveyor belt system.

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THE EFFECT OF MATERIAL PROPERTIES ON MATERIALS HANDLING PROCESSES

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October 1973

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CHAPTER I

RESEARCH OBJECTIVES AND PLANS

1.1 Introduction

The development of large diameter tunnelling machines marks a new era in tunnelling practice. While these machines are capable of excavating hard rock rapidly and continuously, new designs of even greater capacity are being developed and tested. With prototype excavators of extremely high capacity in the testing stage, the problems of materials handling associated with rapid excavation processes are enormous. The research described in this report is an attempt to understand how material properties affect the way they are handled on a conveyor belt.

The present tunnelling machines are an outgrowth of the continuous mining machines developed in the late 40's and early 50's by the coal producers. In need of high productivity per man hour, these companies fostered the development of continuous mining machines which literally rip the coal from the face. The continuous mining machines are equipped with loading devices that move the mined material away from the face and onto an extensible belt conveyor or to a shuttle car behind the miner. The same machines that were developed for coal can also be used for soft rock excavations, for example, in potash.

Having shown that continuous mining equipment was practical, various manufacturers began working on designs for equipment systems that could be used to mine rock of higher compressive strengths. The machines currently in use represent a breakthrough in that rocks with compressive strengths in excess of 25,000 pounds per square inch can be excavated continuously. Tunnelling no longer suffers from the constraints imposed by the cyclic drill-blast method.

The volume of rock produced by continuous excavating machines is largely a function of the speed of the cutting head and the thrust on the

cutting head. Together with the type of cutter head, these parameters control the rate of advance. A number of types of cutter designs have been proposed and tried in practice. These designs have drawn heavily on the technology developed by the oil industry in deep drilling practices through very hard rock formations The particle size distribution and particle shape of the excavated material are, in part at least, dependent on the type of cutter used as well as the relative strength of the material in place. The linear or disc cutter as applied to soft to medium hard formations produces larger particles which tend to be plate-like in shape. In contrast, the tungsten carbide insert cutter which is used in very hard formations tends to produce fine chips of more equal dimensions. Thus, it can be seen that both cutter design and rock strength influence chip shape and size distribution. These can be controlled variables if it can be shown that these properties have an important influence on the materials handling properties.

1.2 Research Objectives

Although the physical properties of bulk materials influence their conveying in all materials handling systems, the emphasis of this study is directed to rapid excavation during tunnelling. A better understanding of the fundamental aspects of the materials-system interface and interactions must be obtained in order to achieve the materials handling capabilities required. In particular, the effect of the physical properties of the excavated material on the handling system must be investigated. The selection of equipment based on experience, tradition or intuition is no longer valid but must be based in part on an analysis of the physical properties of the material to be handled.

The purpose of this research is to attempt to identify the variables which control the material handling processes. The materials of extraction and excavation are man-made. If optimum material characteristics can be found which will enhance the output, it should be possible to modify their properties at or near the face of the excavation to improve their handle-ability. Materials handling systems can be designed around those properties

and variables which are shown to be important in the handling process.

1.3 Research Plan

A small size (model) conveyor has been designed and built for a test system. The model conveyor, which is equipped with an eight-inch belt, is connected to an 18-inch belt, which serves as the return system, thus establishing a closed-loop materials handling system. The small model belt was selected in order to reduce the total amount of material required to fill the system. Numerous problems have developed with the system and these are detailed in a subsequent chapter of this report Included are the details of how these problems have been solved.

A statistical experimental design has been employed for conducting the experimental investigation. This program is very flexible and variables can be added or deleted as necessary during the testing program. Regardless of the number of important variables that are finally formed in the testing program, this method of experimental design will optimize the amount of significant data that can be obtained from a given number of experimental runs. The statistical experimental design offers the best hope of maximizing the evaluation of a multiple-variable experimental system. Details of the experimental design can be found in Appendix A.

In an effort to reduce the size of the test system, several ideas for a conveyor belt simulator have been proposed. One of the designs has been built and has, to a limited degree, been used to study certain aspects of the closed-loop belt conveyor system. The simulator generates, over a short length of belt, the approximate belt conveyor conditions by passing idlers under a stationary belt. Up to four arms can be used on the simulator, each with an attached idler. By varying the speed of rotation of the arms and the number of arms being used, variation in belt speed and idler spacing can be simulated

CHAPTER 2

MODEL BELT CONVEYOR SYSTEM

2.1 Introduction

The technology of the belt conveyor system design has been steadily developed and improved over a period of several decades. Today, in the field of bulk materials handling, belt conveyors are widely accepted as a reliable and economical means of materials handling. With the continuously growing demand for belt conveyors, manufacturers have standardized major system links and, as a rule, only minor modifications are made to suit the practical requirements of the particular installation.

Most of the research carried out on belt conveyor systems as a means of material handling has been by private manufacturers in the field, and directed toward technical developments and improvements of the various components of the system. As a result, comparatively little literature pertaining to optimization analytical studies of conveyor systems is presently available.

In order to accomplish the objectives of this investigation, a large number of experiments on an ideal belt conveyor system was originally considered. However, such an experimental undertaking on an actual belt conveyor system is time consuming, expensive, and requires a large quantity of material to fill the system. It was decided to carry out all the experiments on a reduced size or model closed-loop conveyor system. Details of the model belt conveyor system and equipment modifications required to achieve satisfactory operation of the system are discussed in this chapter.

2.2 Design of Model Conveyor System

A closed-loop model belt conveyor system was designed and built by the Physical Science Laboratory, the University of Wisconsin-Madison, Wisconsin. An eight-inch wide belt conveyor was selected for the model test conveyor, with an 18-inch wide belt which was used for the return conveyor. Both the model conveyor and return conveyor were connected through hopper and chute assemblies at the ends to form a closed-loop system. The model conveyor system was designed to facilitate a study of

most of the machine variables and material variables discussed in Chapter 3. Many of the components were designed, constructed and modified as the need arose, both during construction and after testing began.

The design requirements of the model conveyor system imposed many restrictions on the use of standard conveyor equipment in the system. A case in point is the requirement of adjustability of the inclination of the model conveyor bed. In order to meet this specification, a telescope chute was required, eliminating the possibility of using standard chute components.

2.3 Problems Encountered

2.3.1 Initial Fabrication and Testing Facilities

Because of the unusual requirements of the system, construction of the equipment was considerably delayed. When the construction of the equipment was completed, it was decided to accept the delivery of the equipment on the University of Wisconsin campus. Subsequent modifications of the system components were made as the need arose

Some difficulty was encountered in finding a suitable location for the model conveyor within existing facilities of the College of Engineering. An adequate location was found using a portion of a laboratory in the Department of Metallurgical and Mineral Engineering. At this location, a major constraint was imposed in that dusting during testing must be minimized. Figure 2.1 shows two photographs of the conveyor system after some initial modifications in its present location.

2.3.2 Belt Tracking

After the model conveyor system was assembled and all electrical connections were made, the conveyor was ready for initial shake-down tests. Several minor adjustments and modifications were required to get the equipment in working order. Tracking problems developed with the model conveyor belt because of misalignment of the idlers on the model conveyor bed, the belt was relatively new, and excessive tension on the model conveyor belt. The tracking problem was partly solved when the belt tension was reduced to

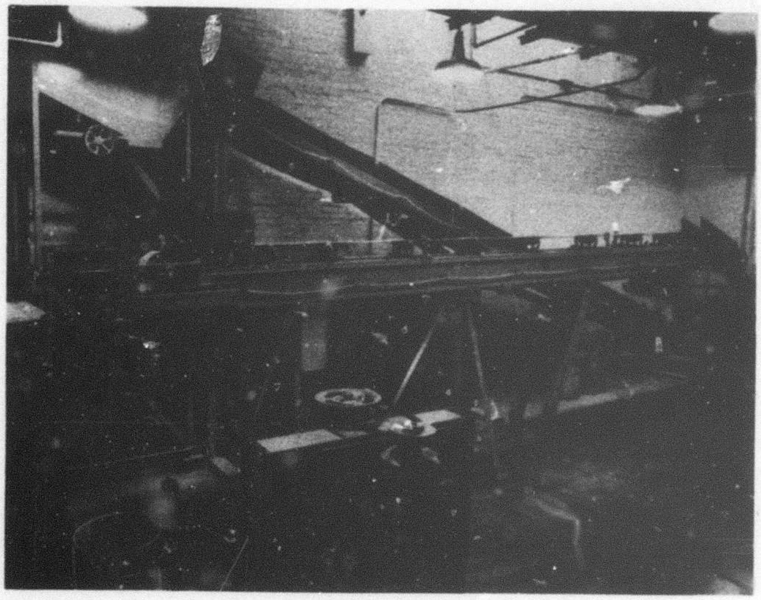


Figure 2.1 Model Conveyor System
(After Initial Modification)

one-half the original value, and special training idlers were mounted on either side of the conveyor bed as shown in the sketch on Figure 2.2. However, after the training idlers were mounted, appreciable rubbing developed on one side of the model conveyor belt. This suggested that the drive pulley may have become misaligned during transportation of the equipment. Subsequent adjustment of the alignment of the drive pulley solved the tracking problem. A similar adjustment was required on the drive pulley of return conveyor to solve the tracking problem of that machine.

2.3.3 Loading and Discharge of Materials

Up to this point the model conveyor system had not been tested with material in the system. It was necessary to use materials other than the bulk samples during the calibration tests in order to avoid exhausting or segregating the prepared muck samples prior to the actual production tests. During the calibration tests, several additional problems in the component design were discovered during a short period of operation of the system with sand as the material medium. The problems encountered in maintaining a steady flow of material through the system were centered at the discharge and loading ends of the model conveyor. Figure 2.3 shows a schematic diagram of the model conveyor system before modification.

2.3.3.1 Problems with the discharge end of the model conveyor.

The first major problem was created by the original design of the receiving hopper. The inclination of the walls of the hopper bottom were designed on the assumption that the angle of repose for the dry material would be approximately 20°; however, the actual angle of repose for the sand (slightly moist) proved to be approximately 27°. As a result, the hopper walls were not sloped at a sufficiently steep angle and material accumulated in the receiving hopper (Point AA, Figure 2 3). One obvious modification of the existing hopper; i e., steepening the walls, was impossible since the difference in height between the model conveyor discharge end in the horizontal position and the lower end of the return conveyor is fixed. In order to overcome the problem, the receiving hopper was eliminated and a loading chute was constructed leading directly

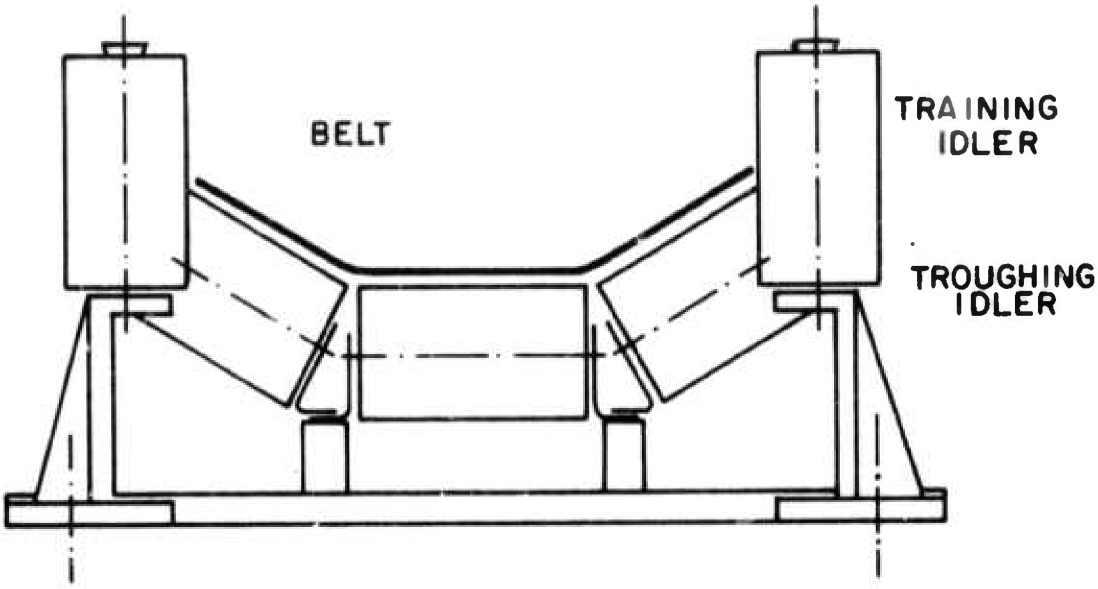


FIGURE 2.2

TRAINING IDLER IN POSITION.
POSITIVE ACTION TYPE.

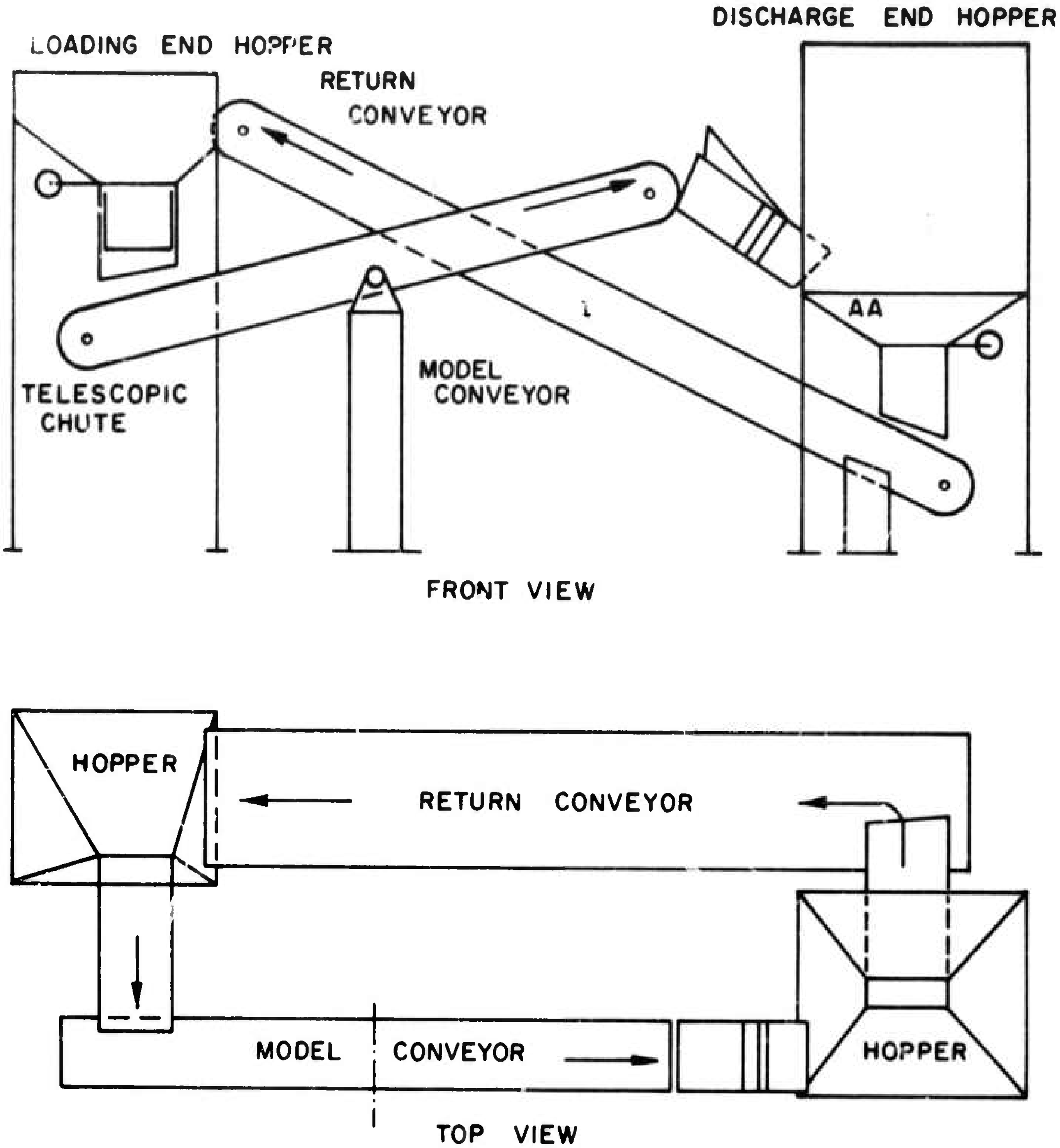


FIGURE 2.3

BLOCK DIAGRAM OF CONVEYOR SYSTEM (BEFORE MODIFICATIONS).

from the telescopic chute to the return conveyor. The chute was built from light gauge galvanized steel sheets and performed quite satisfactorily up to two-thirds of the loading capacity of the model conveyor.

A second problem developed at the transfer point from the loading chute to the return conveyor. The use of a wing take-up pulley on the lower end of the return conveyor caused considerable vibration of the belt and excessive spillage at the loading point. This problem was solved by mounting a straight roller between the wing take-up pulley and the loading point and on top of the belt which effectively reduced the vibrations to an acceptable level. The same problem occurred at the loading end of the model conveyor and was resolved in the same manner.

2.3.3.2 Problems with the loading end of the model conveyor.

The inclination of the model conveyor bed is adjustable within a range of 0° to 20°. This unusual feature requires the loading end to extend 40 inches downward from the horizontal position in order to achieve the maximum inclination of 20°. As a result, the inclination of the telescopic chute connecting the loading end hopper and skirts must vary from 20° to 61° with the horizontal. The slope of the telescopic loading chute becomes very steep with the model conveyor bed inclination as low as 8°, causing the material to impact the conveyor belt with very high momentum. Furthermore, the horizontal component of the flow velocity vector was perpendicular to the direction of the belt travel. These conditions made it extremely difficult to load the model conveyor belt uniformly and without spillage. The problem was resolved by fabricating adjustable baffle plates on the loading chute as shown on Figure 2.4. Except for the time consuming adjustments required with each change in inclination of the conveyor bed, the loading chute was found to be satisfactory.

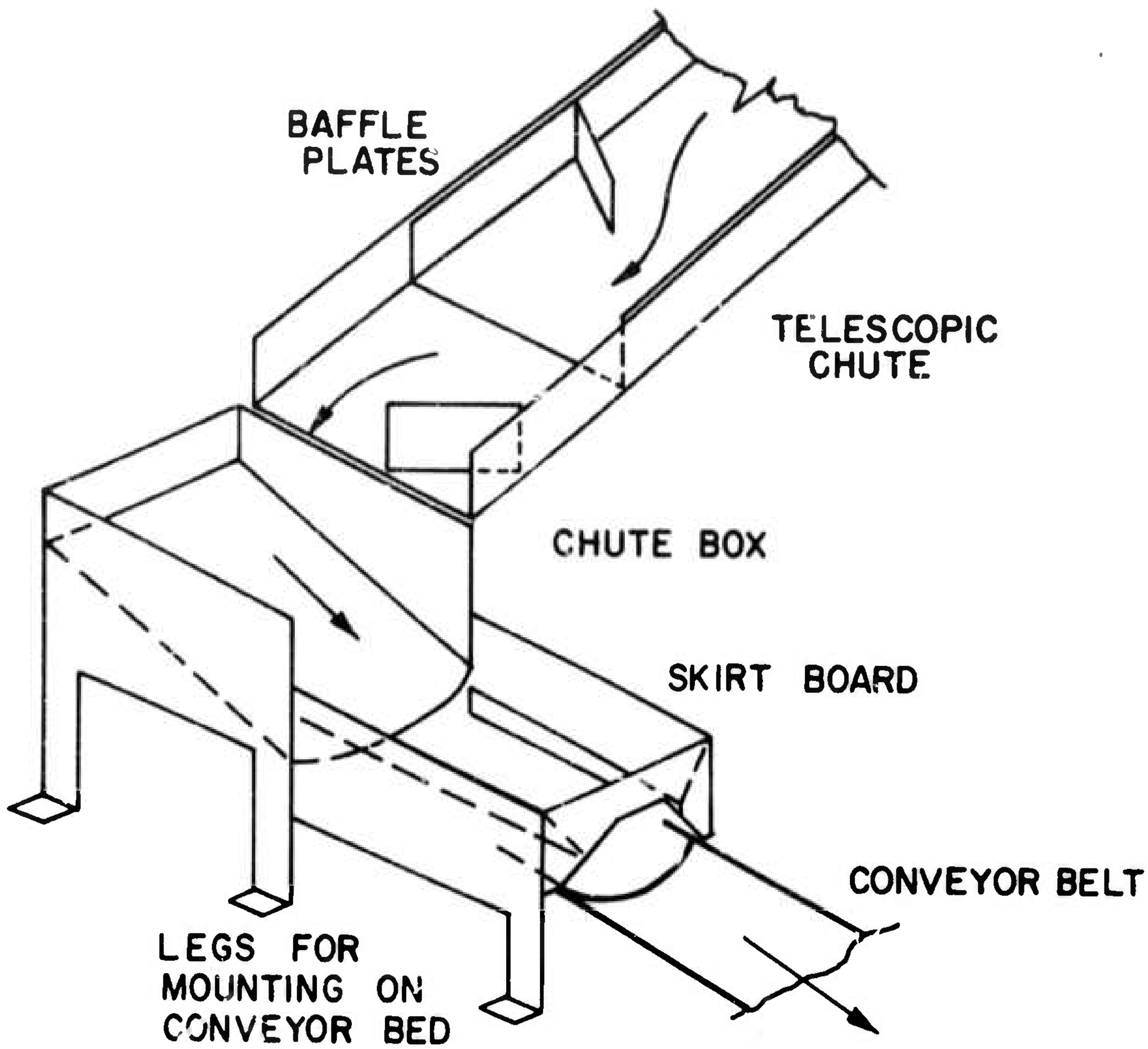


FIGURE 2.4

MODIFIED LOADING END LAYOUT

A second major difficulty encountered at the loading end of the model conveyor involved the design of the skirts and skirt board. The original design did not provide uniform and smooth loading on the belt because the momentum of the material approaching the belt was at right angle to the belt travel. The problem was temporarily resolved by constructing an additional chute box located behind the skirts as shown in Figure 2.4. In the final configuration, the material is first dropped in the chute box and from there feeds onto the belt with a small momentum in the direction of the belt movement. This arrangement has proven to be quite satisfactory and produces uniform loading of the belt up to two-thirds of the maximum capacity.

After the necessary modifications on the model conveyor system had been accomplished, a series of tests was run to evaluate the overall performance characteristics of the conveyor system. A detailed discussion and analysis of the experimental study is presented in Section 3.3.

2.3.4 Final Modifications

Examining the results of the initial experimental study (Section 3.3) it was observed that at a drive pulley speed of 130 rpm, the material flow-through galvanized steel chute near the discharge end was not satisfactory. The rate of flow of the material from the chute on the return conveyor was less than the rate of flow from the model conveyor to the chute resulting in "dead pockets." This would be a serious drawback when the belt was running at a higher capacity. This difficulty would be further amplified when wet material was used

Similar "dead pockets" of material were observed at the loading end hopper. Also the rate of loading on the conveyor belt was reduced due to the jamming of the material in the telescopic chute and skirt board. At full capacity, since the material had to alter its course of direction 90° to get on the belt, the velocity was reduced resulting in the conveyor belt running at a very low capacity.

In order to overcome these difficulties when the conveyor was run at high capacities, the following final modifications were made.

2.3.4.1 New design of discharge end hopper.

Figure 2.5 is a photograph of the modified model conveyor system. The galvanized steel sheet chute is replaced by a discharge end hopper. This hopper was designed to be used when the model conveyor was set between 0° and 10° inclination. The movement of the chute connector to the model conveyor system was controlled by a cable passing through the top end of the hopper. This control helped to vary the steepness of the chute depending on the requirements of the experiments. The slope of the chute was increased when handling large quantities of materials and/or when moist materials were used. The top of the chute was covered which helped control dust during material transfer.

2.3.4.2 Re-positioning the loading end hopper.

Even though the volume of the loading end hopper was sufficient to load the belt to its full capacity, this was seldom a case. The sides of the hopper lacked the adequate slope to move the material fast enough to maintain continuity at full capacity. Hence it was felt that the material should be accelerated when it was discharged in the hopper. This was done in two steps. Firstly, the "throw" of the material from the return conveyor (running at constant speed) was increased by changing the size of the drive pulley of the return conveyor. Secondly, this "drop" (of material from the return conveyor) occurred in a sheet having a steep angle. This helped to move the material to the exit in the hopper at a faster rate.

The accumulation of the material in the telescopic chute was due to the loss of velocity at the 90° turn. Hence it was decided to re-position the loading end hopper. This position enabled

Figure 2.5 Model Conveyor System
(After final modification)

the material to move from the hopper to the telescopic chute in the same direction as that of the conveyor belt. This also helped in the uniform loading of the belt and prevented excessive spillage.

For wet material the friction was sufficient to reduce the flow of material in the hoppers and chutes. Thin sheets of teflon were glued to the surfaces of hoppers and chutes. This reduced the flow-friction and permitted the use of wet material.

The performance due to the above modifications was felt to be satisfactory for commencement of the experimentation.

2.4 Conveyor Belt Simulator

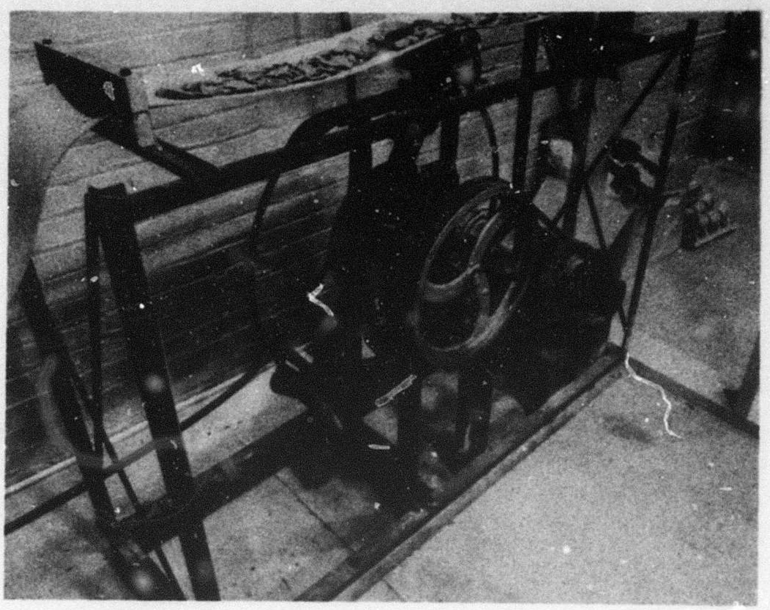
Several concepts of conveyor belt simulation were considered before developing the simulator used in the tests reported here. The purpose of the simulation program was two-fold. Considerations of scaling factors indicated that vertical motions experienced by the material on the belt is a fundamental factor determining the handling characteristics. Secondly, constructing an efficient experimental design requires preliminary knowledge of the variables, their possible ranges, and the enteractions with other variables. For these reasons, the program of developing a simulator was pursued in two stages.

The first simulator consisted of a container designed to approximate the geometry of a conveyor belt cross section. The sides were adjustable so that various troughing angles could be obtained. The material was placed in the container at the angle of repose and the whole apparatus was vibrated by an electromagnetic shaker with the frequency dependent on the mass of the sample and the amplitude of vibration dependent on the frequency. The frequency of vibration was increased to the point where the material became severely agitated. Profiles of the material before and after testing were made for comparative purposes.

While this device did not simulate a conveyor, the following conclusions were made:

1. At low frequencies relatively large amplitude could be tolerated before significant alteration of the sample cross section occurred.
2. As the frequency of vibration increased less amplitude was needed to alter the cross section.
3. Peak vertical acceleration is the major factor controlling the ultimate angle of surcharge achieved by the material when subjected to vertical vibration.

To more nearly approximate a moving belt, the simulator shown in Figure 2.6 was designed and built. It consists of up to four rotating arms, to which an idler can be attached and a piece of stationary belt. The bulk of each revolution is circular but as the idler passes under the short piece of belt the track is straight. The use of one or more idler-arm units rotating at variable speeds is analogous to changing the belt speed and changing the idler spacing. Although the design of the simulator is not as versatile as that of the model conveyor, in terms of different variables of the conveyor system, the variables of idler spacing, belt speed, and the moisture condition of the material were studied and are reported in Section 3.5.2 of this report.



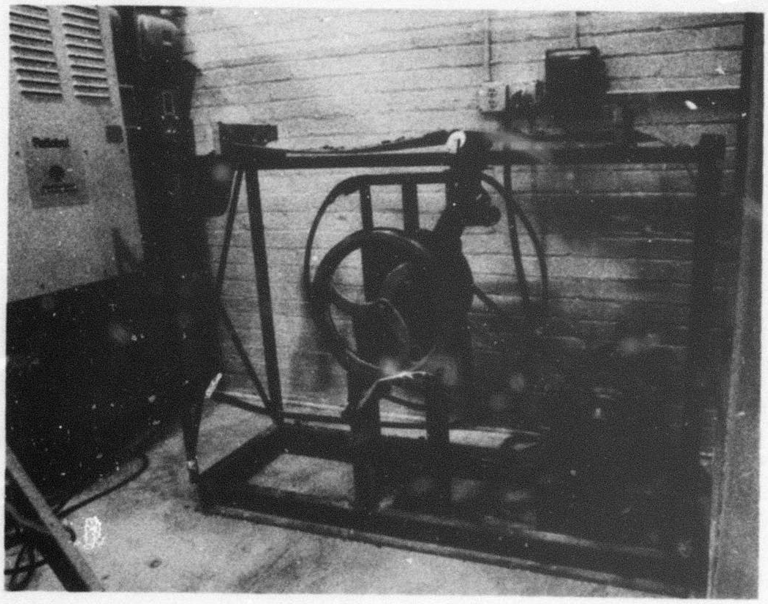


Figure 2.6. Belt Conveyor System Simulator

CHAPTER 3

EXPERIMENTAL INVESTIGATIONS

3.1 General Considerations

In order to investigate the influence of material properties on the material handling characteristics, a series of experiments were performed using the model belt conveyor and conveyor simulator described in Chapter 2.

The relationship which might exist between the performance of model conveyor or the conveyor simulator and a full-scale belt conveyor installation involves unknown scaling factors. In the early stages of this investigation, it was anticipated that a study of these scaling factors might be undertaken within the scope of this investigation. However, because of the difficulties encountered in designing and constructing the experimental equipment and the lack of a readily available full-scale conveyor installation that could be utilized in a comparative study, the scaling factors were not evaluated.

In view of the uncertainty between effects observed in model tests and full-scale installations, the results of model tests, as carried out in this investigation, are useful primarily in a qualitative sense. It is believed that the general trends observed in the model tests are also valid for full-scale installations, although the magnitude of the effects may differ substantially. It is also believed that the methodology developed for performing and analyzing the model tests may be quite useful in the design (or modification) of full-scale installations.

3.2 Belt Conveyor System Variables

A belt conveyor system for materials handling is a complex installation involving a large number and variety of variables. Moreover, it may be anticipated that the overall economy and efficiency of the system will be influenced not only by the individual variables but also by the interaction effects of

any one of the variables on another.

A complete listing of the variables that would influence the performance of any belt conveyor system is impractical for the purposes of this investigation. However, certain variables associated with the equipment itself and the material to be transported are common to most systems. The following is a list of the most common and easily identifiable system variables.

Equipment Variables:

(1) Belt speed

(2) Belt inclination

(3) Belt material

(4) Belt tension

(5) Idler spacing

(6) Troughing angle

(7) Cross sectional configuration of conveyor bed

Material Variables:

(8) Particle size distribution

(9) Particle shape

(10) Angle of interval friction

(11) Moisture content

The effects of several of these variables have been investigated in this study, the results of which are presented in a subsequent section of this report.

3.3 Experimental Design

Due to the large number of variables involved, a considerable amount of experimental data is required to evaluate the effects. Therefore, the collection and analysis of the data requires a systematic experimental program. A statistical experimental design provides a convenient and economical approach for this purpose. Advantages of the statistical experimental design approach include minimizing the number of tests required, systematic procedures for

analysis and interpretation of data, reduced experimental costs, and greater overall efficiency of the experimental program. A summary of the theory and methodology of this method is presented in an Appendix A.

3.4 Testing Program

As previously noted, the experimental program was carried out using two experimental devices which were designed and constructed as part of this study; i.e., a model belt conveyor and a conveyor simulator.

The model conveyor has the advantage of including a greater number of equipment variables which is a valuable feature for studying interaction effects between equipment variables and material variables. It also obviously provides a more realistic approximation of the full-scale conveyor system. The primary disadvantages of the model conveyor are the complexity of the system, cost of construction, and the greater difficulty of isolating the effects of individual variables.

The conveyor simulator offers an economical and easy-to-use alternative to the model conveyor. The conveyor simulator greatly reduces the time and expense of the testing program and the degree of experimental control is far superior to the model conveyor. The disadvantages of this system are the elimination of many of the effects that may influence the performance of an actual conveyor system and the difficulty of matching the mechanics of belt conveyor action.

3.4.1 Materials Tested

The primary objective of this study was to investigate the effects of material properties on the materials handling characteristics on belt conveyors. Early in the investigation, samples of materials obtained from various tunneling projects were collected and tested. The mechanical properties of these materials are presented in Appendix B.

For the experimental program, the materials selected consisted of the crushed rock obtained from a tunneling project in Milwaukee, Wisconsin and a washed, bank run sand. These materials were chosen to provide contrasting material properties. The crushed rock consists of angular particles, is very well graded, and has a high angle of repose (approximately 45 degrees). The sand has rounded to subrounded particles, relatively uniform particle size, and has an angle of repose of approximately 34 degrees. The range of material properties represented by these two materials is considered to be representative of the range that would normally be encountered in materials handling applications involving natural materials.

The two contrasting materials were tested in both "wet" and dry conditions. However, since both materials are relatively coarse-grained, their moisture retention capabilities are quite low and the resulting contrast between the wet and dry states was relatively minor.

3.4.2 Model Belt Conveyor Tests

Following the initial "shakedown tests," two series of tests were performed using the model conveyor. The first series consisted of sixteen tests involving six variables. The low and high levels of the six variables used in the factorial design are listed below.

Variable	Level: Low	Level: High
A - Belt Tension	82 lbs	122 lbs.
B - Troughing Angle	20°	35°
C - Bed Inclination	5°	9°
D - Type of Material	Crushed Rock	Sand
E - Idler Spacing	2 ft.	4 ft.
F - Moisture Condition	Dry	Wet

Each series of tests was conducted at three belt speeds; i.e., 303, 433, and 562 feet per minute.

A 2^{6-2} fractional factorial, resolution IV, design was used, the matrix design for which is shown in Table 3.1. Since the experimental design was resolution IV, some of the two-factor interaction effects are confounded with other two-factor interactions. However, this design approach is far more efficient than investigating the variables one at a time. It may be assumed that three factor and higher order interactions are negligible.

The results of the first series of tests on the model conveyor (reported and discussed in a subsequent section of this report) produced considerable difficulty in interpretation due to the complex intereaction effects of the several variables involved. Therefore, a second series of tests was performed, limiting the number of variables to three and concentrating of the effects of material properties. The low and high levels of the three variables considered in the second series of tests are listed below.

Variable	Level Low	Level High
A - Belt Tension	82 lbs.	142 lbs.
B - Moisture Condition	Dry	Wet
C - Type of Material	Crushed Rock	Sand

The tests were conducted at belt speeds of 368 and 525 feet per minute, the bed inclination was zero degrees, the idler spacing was 2 feet, and the troughing angle was 20 degrees. The design matrix for this series of tests is presented in Table 3.2.

In the model belt conveyor tests, the "response" of the system was evaluated in terms of the relative amount of material transported at a given belt speed. Although this interpretation of "response" does not consider many factors which would be important in an actual installation; e.g., power consumption, belt wear, etc., it provides a consistent method for evaluating the ability of the system to transport material at a particular belt speed.

Due to certain limitations in the design of the model conveyor, it was not convenient to either control the total volume of material in the system or

Test No.	Variables						Two-Factor Interactions														
	A	B	C	D	E	F	AB	AC	AD	AE	AF	BC	BD	BE	BF	CD	CE	CF	DE	DF	EF
1	-	-	-	-	+	-	+	+	+	-	+	+	+	-	+	+	-	+	-	+	-
2	+	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+
3	-	+	-	-	-	+	-	+	+	+	-	-	-	-	+	+	+	-	+	-	-
4	+	+	-	-	+	+	+	-	-	+	+	-	-	+	+	+	-	-	-	-	+
5	-	-	+	-	-	+	+	-	+	+	-	-	+	+	-	-	-	+	+	-	-
6	+	-	+	-	+	+	-	+	+	+	-	+	-	-	-	+	+	+	-	-	+
7	-	+	+	-	+	-	-	-	+	-	+	+	-	+	-	-	+	-	-	+	-
8	+	+	+	-	-	-	+	+	-	-	-	+	-	-	-	-	-	-	+	+	+
9	-	-	-	+	-	+	+	+	-	+	-	+	-	+	-	-	+	-	-	+	-
10	+	-	-	+	+	+	-	-	+	+	+	+	-	-	-	-	-	-	+	+	+
11	-	+	-	+	+	-	-	+	-	-	+	-	+	+	-	-	-	+	+	-	-
12	+	+	-	+	-	-	+	-	+	-	-	-	+	-	-	-	+	+	-	-	+
13	-	-	+	+	+	-	+	-	-	-	+	-	-	-	+	+	+	-	+	-	-
14	+	-	+	+	-	-	-	+	+	-	-	-	-	+	+	+	-	-	-	-	+
15	-	+	+	+	-	+	-	-	-	+	-	+	+	-	+	+	-	+	-	+	-
16	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Variables:

A - Belt Tension

B - Troughing Angle

C - Bed Inclination

D - Type of Material

E - Idler Spacing

F - Moisture Condition

Table 3.1. Matrix Design for First Series of Tests.

	Variables			Two-Factor Interactions		
Test No.	A	B	C	AB	AC	BC
1	-	-	-	+	+	+
2	+	-	-	-	-	+
3	-	+	-	-	+	-
4	+	+	-	+	-	-
5	-	-	+	+	-	-
6	+	-	+	-	+	-
7	-	+	+	-	-	+
8	+	+	+	+	+	+

Table 3.2. Matrix Design for Second Series of Tests

Variables:

A - Belt Tension

B - Moisture Condition

C - Type of Material

to load the system to its maximum capacity. Therefore, a method was devised to determine the amount of material on the belt at any given time relative to a theoretical maximum. The theoretical maximum in this context is the amount of material the belt would carry if the material maintained a certain ideal cross sectional profile. The "ideal profile" was obtained using the method presented by the Conveyor Equipment Manufacturers Association. The surcharge angle used in the determination of the ideal profile was assumed to 15 degrees less than the angle of repose of the material. The resulting ideal profiles for the materials tested are shown in Figure 3.1.

The areas of the actual cross sectional profiles were determined using a pentograph device after the belt was stopped. Figure 3.2 shows typical profiles traced near loading and discharge ends. The areas were determined at two or more locations to be certain that a representative area was obtained. A typical example of the measured profile and ideal profile is shown in Figure 3.3. The ratio of the actual profile area to the area of the ideal profile (A_a/A_i) was then used as the measure of the system response.

3.4.3 Conveyor Simulator Tests

The design, construction, and testing programs for the model conveyor and conveyor simulator were carried out as parallel activities during this study. However, because of the greater emphasis placed on the model conveyor system and the percentage of effort required in its development, the development of the conveyor simulator only reached a preliminary stage. Only one material (sand) was tested in the conveyor simulator, and, therefore, the effects of material properties could not be evaluated. However, the preliminary results indicate that the simulator may have considerable promise as a device for investigating specific aspects of conveyor systems.

The variables considered in the simulator tests included belt speed, idler spacing, and the moisture condition of the material. The experimental design and evaluation of results were carried out using the same statistical approach described for the model conveyor.

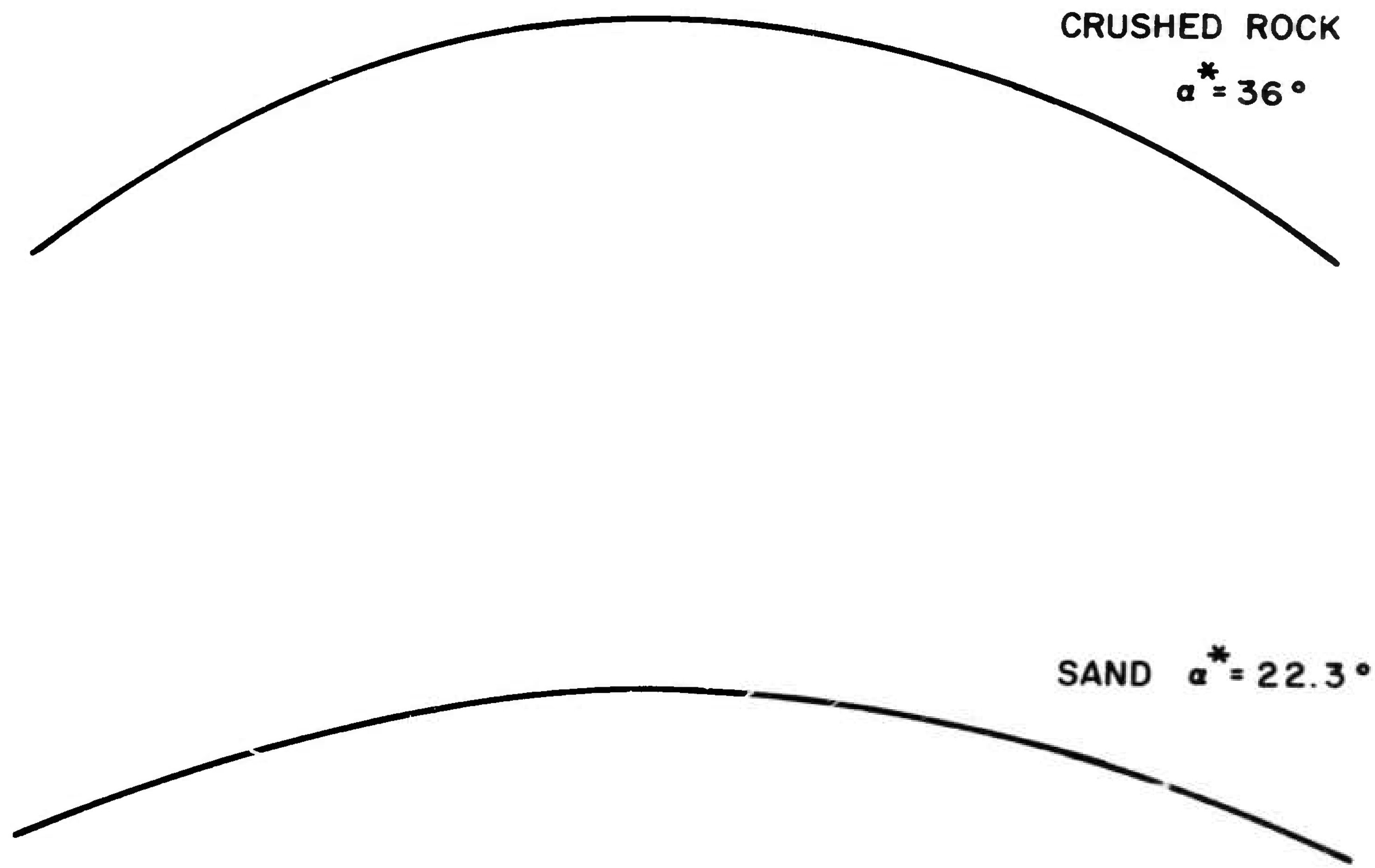
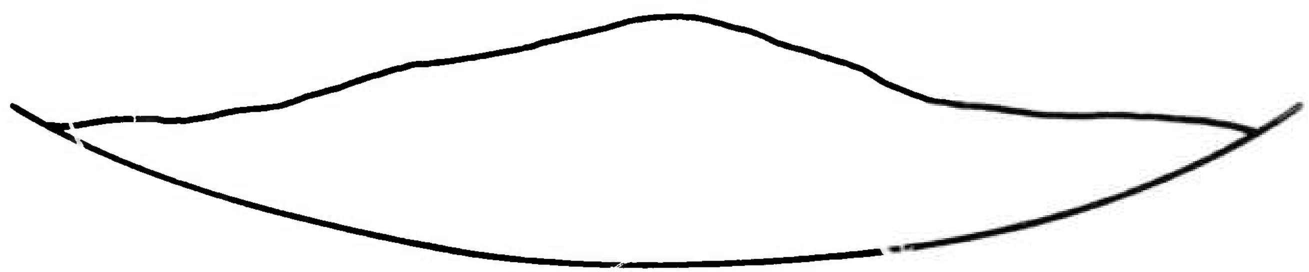
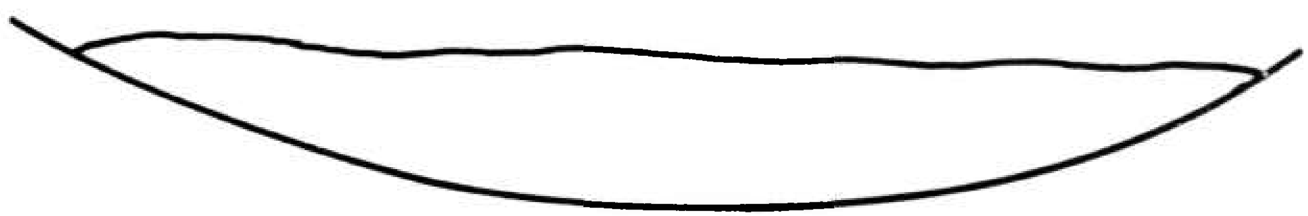


FIGURE 3.1 IDEAL PROFILES FROM MATERIALS TESTED.

a = Ideal surcharge angle



PROFILE AT THE LOADING END



PROFILE AT THE DISCHARGE END

FIGURE 3.2 A TYPICAL TRACE OF THE PROFILE OF THE MATERIAL TAKEN FROM THE EXPERIMENTS.

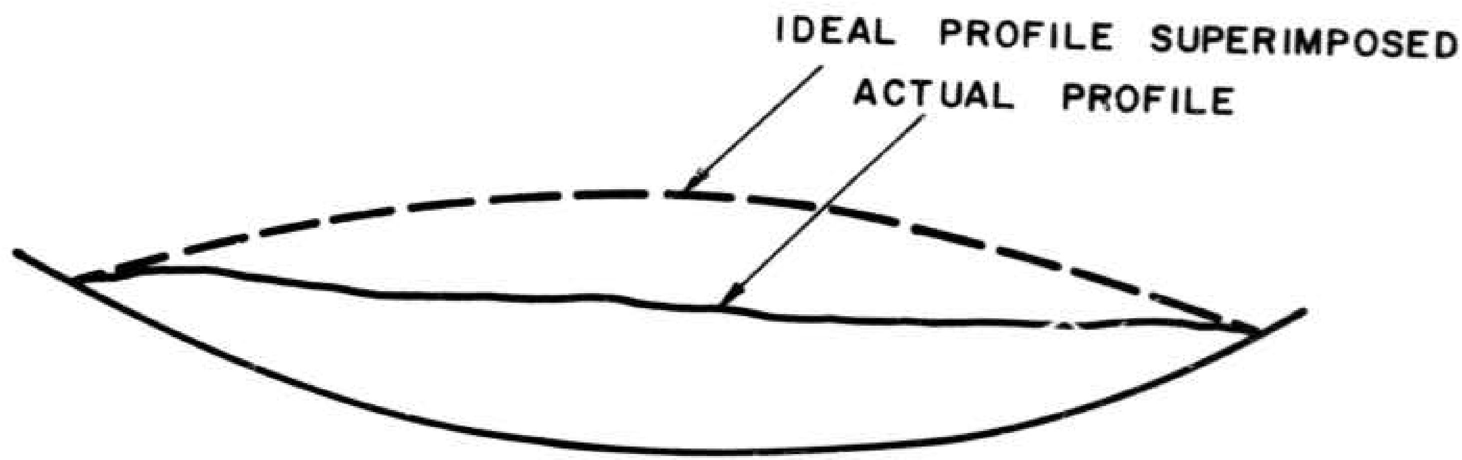


FIGURE 3.3 TYPICAL TRACE OF IDEAL AND ACTUAL PROFILE FROM WHICH AREA RATIOS WERE CALCULATED.

3.5 Results

3.5.1 Model Conveyor System

The results obtained from the first series of sixteen tests at each of three belt speeds are presented in Table 3.3. The results are presented in terms of the Area Ratio (A_a/A_i) determined by the method described in Section 3.4.2 of this report.

The main effects and interaction effects were computed for the results presented in Table 3.4. The elements of column A in Table 3.1 are multiplied with the corresponding elements of the columns in Table 3.3. The algebraic sum of these quantities divided by eight yields the main effect due to the Variable A at a particular belt speed. For example, the main effect due to variable A, the belt tension at a belt speed of 303 feet per minute is calculated as follows:

$$X = - 52.63 - 54.13 - 56.68 - 41.12 - 58.61 - 58.13 - 57.20 - 65.85$$

$$Y = 39.51 + 46.63 + 61.29 + 55.1 + 60.96 + 60.86 + 67.6 + 65.74$$

The quantities X/8 and Y/8 give the high and low values and the main effect is the difference. In the preceding example, the high value is 57.21 and the low values are 55.54 and the main effect is +1.67. The high and low values and the main effects for the first series of model conveyor tests are presented in Table 3.4.

The "effect" of a variable represents the change in response produced by a change in the level of the variable. When a factor is examined at two levels only, as in the present case, the effect is simply the difference between the average response of all tests conducted at the higher level. The high value is the average of the area ratios at the higher belt tension of 122 lbs, and the low value is the average of the area ratios at the lower belt tension of 82 lbs. Therefore, the main effect is the difference in area of the material at these two tensions. The positive sign indicates that the area is greater at higher belt tension than at a lower belt tension for the given speed of 303 feet per minute.

	AREA RATIO A_a/A_i %		
Test No.	303 fpm	433 fpm	562 fpm
1	52.63%	37.43%	42.22%
2	39.51%	36.76%	43.12%
3	54.13%	41.29%	40.74%
4	46.63%	46.21%	49.40%
5	56.68%	50.83%	42.30%
6	61.29%	51.7%	35%
7	41.12%	58.29%	44.47%
8	55.1%	76.13%	65.95%
9	58.6%	52.43%	49.02%
10	60.96%	53.34%	49.35%
11	58.13%	55.42%	45.27%
12	60.86%	44.15%	48.66%
13	57.20%	50.42%	45.89%
14	67.6%	48.43%	49.08%
15	65.85%	57.54%	47.72%
16	65.74%	53.28%	44.33%

Table 3.3. Area Ratios for 16 Tests.

TABLE 3.4. Main Effects

BELT SPEED 303 fpm

		A	B	C	D	E	F	Main Effect
A	Hi	57.21						
	Low	55.54						+1.67
B	Hi	56.68	55.94					
	Low	56.07	56.81					-0.87
C	Hi	59.15	54.94	58.82				
	Low	54.80	57.81	53.93				+4.89
D	Hi	57.46	57.59	56.16	61.87			
	Low	55.29	55.17	56.59	50.89			+10.98
E	Hi	58.73	54.25	54.81	55.93	55.46		
	Low	54.02	58.50	57.95	56.82	57.29		-1.83
F	Hi	55.46	56.16	57.59	54.94	57.21	58.72	
	Low	57.29	56.59	55.17	54.81	55.54	54.02	+4.70

BELT SPEED 433 fpm

		A	B	C	D	E	F	Main Effect
A	Hi	51 25						
	Low	50.42						+1.83
B	Hi	51.32	54.04					
	Low	50.35	47.63					+6.41
C	Hi	52.01	53.15	55.79				
	Low	49.65	48.52	45.87				+9.92
D	Hi	48.38	48.39	46.38	44.65			
	Low	53.29	53.28	55.29	49.83			-5.18
E	Hi	50.83	50.21	48.50	52.15	50.64		
	Low	50.84	51.46	53.17	49.52	50.96		-0.32
F	Hi	50.72	46.38	48.39	53.15	51.25	50.83	
	Low	50.94	55.29	53.28	48.52	50.39	50.84	-0.01

TABLE 3.4. Main Effects (Continued)

BELT SPEED 562 fpm

		A	B	C	D	E	F	Main Effect
A	Hi	44.11						
	Low	44.70						+3.41
B	Hi	48.60	48.32					
	Low	44.34	44.50					+3.82
C	Hi	46.46	48.27	46.84				
	Low	46.36	44.54	45.97				+0.87
D	Hi	45.14	43.58	45.31	47.41			
	Low	47.67	49.24	47.50	45.4			+2.01
E	Hi	44.73	45.87	43.92	48.38	44.49		
	Low	48.09	46.94	48.91	45.70	48.32		-3.83
F	Hi	44.49	45.31	43.58	49.53	48.11	44.73	
	Low	48.32	47.50	49.25	44.52	44.70	48.08	-3.35

Variables:

A - Belt Tension

B - Troughing Angle

C - Bed Inclination

D - Type of Material

E - Idler Spacing

F - Moisture Condition

The effect of one factor also depends on the level of other factors and the factors are said to interact. The interaction effects were also calculated in the manner described above. The main effects and two factor interactions are summarized in Table 3.5.

A multiple linear regression analysis was carried out on the sample data and results of the analysis are presented in Table 3.6. The computer program used here is part of the library of available programs at the Madison Area Computing Center on the campus of the University of Wisconsin.

Some tentative conclusions can be drawn from the results For example, the main effect due to variable D, the type of material, is very significant at all speeds. But the effect is not consistent in this series of tests. Similar inconsistencies were found in the effects of other variables. Therefore, in an effort to improve the consistency of the results and concentrate attention on the effects of the material properties, a second series of tests was performed involving only belt tension, type of material, and moisture condition as variables.

The area ratios of the second series of model conveyor tests are presented in Table 3.7. The main effects and two factor interactions computed from these results are presented in Table 3.8. Statistical analyses of the data were performed and the results are presented in Table 3.9.

The consistency of the results is considerably improved in the second series of tests. The main reasons for the improvement are apparently due to limiting the number of variables considered and improved technique of operating the equipment and measuring the results; i.e., elimination of some of the experimental error. The effects on the response of the model conveyor system, as observed in the two series of tests reported herein, are summarized in the following paragraphs.

Of all the variables considered the type of material produced the greatest effect on the response. Although the effect diminishes with increasing belt speed it is reasonably consistent over the range of speeds tested. However it is to be expected that the increasing disturbance of the material on the belt as the speed increases would have a tendency to negate the effects of material characteristics. In view of the fact that the greatest effect on the response

Table 3.5. Summary of Main Effects and Interactions for 16 Test Experiment.

	BELT SPEED fpm		
Effects	303	433	562
A	+1.67	+0.83	+3.41
B	-0.87	+6.41	+3.82
C	+4.89	+9.92	+0.87
D	+10.98	-5.18	+2.01
E	-1.83	-0.32	-3.83
F	+4.70	-0.01	-3.35
AB	+0.61	+0.97	+4.26
AC	+4.35	+2.36	+0.10
AD	+2.17	-4.91	-2.53
AE	+4.71	-0.01	-3.36
AF	-1.83	-0.22	-3.83
BC	-2.87	+4.63	+3.73
BD	+2.42	-4.89	-5.66
BE	-4.25	-1.25	-1.07
BF	-0.43	-8.91	-2.19
CD	-0.43	-8.91	-2.19
CE	-3.14	-4.67	-4.99
CF	+2.42	-4.89	-5.67
DE	-0.89	+2.63	+2.68
DF	+0.13	+4.63	+5.01
EF	+1.67	+0.86	+3.41

Variables:

A - Belt Tension

B - Troughing Angle

C - Bed Inclination

D - Type of Material

E - Idler Spacing

F - Moisture Condition

		BELT SPEED fpm	
	303	432	562
1. F - Ratio	3.3	1.17	0.84
2. Standard error of the estimate	5.92	9.07	6.75
3. R^2 - Multiple correlation coefficient	0.83	0.662	0.60

Table 3.6. Multiple Regression Analysis of Data From 16 Test Experiment.

Test No.	AREA RATIO AA/AI% 368 fpm	525 fpm
1	59.48%	61.66%
2	62.40%	59.16%
3	62.99%	58.38%
4	43.30%	46.96%
5	59.61%	59.72%
6	71.42%	65.89%
7	81.39%	75.96%
8	84.73%	83.14%

Table 3.7 Area Ratios for 8 tests.

BELT SPEED 368 fpm

		A	B	C	Main Effect
A	Hi	65.462			
	Low	65.867			-0.405
B	Hi	61.78	68.102		
	Low	69.55	63.227		4.875
C	Hi	69.655	72.00	74.287	
	Low	61.675	59.33	57.050	17.237

BELT SPEED 525 fpm

		A	B	C	Main Effect
A	Hi	63.787			
	Low	63.93			-0.143
B	Hi	62.87	66.110		
	Low	64.897	61.608		4.512
C	Hi	67.267	69.98	71.177	
	Low	60.45	57.737	56.54	14.637

Effects	BELT SPEED 368 fpm	BELT SPEED 525 fpm
A	-0.405	-0.143
B	4.875	4.512
C	17.237	14.637
AB	-7.77	-1.977
AC	7.98	6.81
BC	12.67	12.24

Table 3.8. Summary of Main Effects and Two Factor Interactions for 8 Test Experiment.

Variables:

A - Belt Tension

B - Moisture Content

C - Types of Material

		BELT SPEED fpm	
		368	525
1	F - Ratio	1.44	1.52
2	Standard error of the estimate	12.18	10.15
3	R^2-Multiple co-relation co-efficient	0.72	0.73

Table 3.9. Multiple Linear Regression Analysis of Data From 8 Test Experiment.

of the system is due to the type of material being transported, it follows that material properties should be a major consideration in design of materials handling systems.

The effect of the moisture condition of the material also proved to be significant. This result is actually somewhat unexpected because of the low moisture retention capacities of the materials tested. It appears obvious that more fine-grained materials and/or more cohesive materials would be far more sensitive to moisture content.

For a given type of material and moisture condition, the effects of the equipment variables were relatively minor for the range of variables tested. Because of the difficulty of extrapolating the range of variables in the model conveyor to a full-scale installation, it would be premature to apply the same conclusion to a full-scale installation. Nevertheless, it seems reasonable to assume that the effect of equipment variables would not completely overshadow the effects of material variables in a full-scale installation.

3.5.2 Conveyor Simulator

The results obtained from the conveyor simulator tests are presented in Table 3.10. Because of equipment limitations and time available, the only variables considered in this portion of the study were the belt speed, idler spacing, and moisture condition of the material. The results are presented in terms of the surcharge angle of the material measured after the apparatus has been run long enough to reach an equilibrium condition. The results of multiple regression analysis of the data are presented in Table 3.11.

The conveyor simulator tests show the same general trend as the model conveyor tests for the variables considered; i.e., the surcharge angle (which is related to the area ratio) decreases with increased idler spacing and/or belt speed. In these tests, the effect of moisture condition was insignificant. However, because of the relatively coarse-grained nature of the material, it could be anticipated that this effect would be small.

		Dry Sample			Wet Sample		
		Idler Spacing			Idler Spacing		
		4.71'	3.14'	2.38'	4.71'	3.14'	2.38'
Belt Speeds (fpm)	232	8*	13	16	8	14	15
	201	5	7	10	5	7	11
	378	1	3	5	1	2	6

*Surcharge angle (degrees)

Table 3.10. Results of Conveyor Simulator Tests.

1. F - Ratio	4.91
2. Significance level of the regression	0.008
3. Standard error of the estimate	3.66
4. R^2-Multiple correlation coefficient	0.863
5. Significance level of the variables	
A) Moisture content	0.182
B) Idler spacing	0.064
C) Belt speed	0.611

Table 3.11. Multiple Linear Regression Analysis of Conveyor Simulator Data.

The preliminary results obtained by the conveyor simulator tests show general agreement with the results of the model conveyor tests. Therefore, in view of the greatly reduced costs of design and construction and the ease of testing, it appears that the conveyor simulator has considerable potential as a device for investigating the response of conveyor systems.

CHAPTER 4

CONCLUSIONS

4.1 Model Conveyor System

Based on the data presented on the various tests performed using the model conveyor system, the following conclusions can be drawn:

1. Of all the variables considered, the type of material produces the greatest effect on the response. This effect diminishes with increasing belt speed.
2. The effect of the moisture condition of the material proved to be significant even though the moisture retention capacities of the materials tested were very low.
3. For a given type of material and moisture condition, the effects of the equipment variables were relatively minor for the range in variables tested.
4. Additional development and testing should be done if funds are available.

Since the greatest effect on the response of the system is due to the type of material being transported, material properties should be a major consideration in design of materials handling systems. Because of the difficulty of extrapolating the range of variables used in the model conveyor to a full scale installation, the preceeding conclusions should be applied to a full scale installation with considerable caution.

4.2 Conveyor Belt Simulator

The actual development of a conveyor belt simulator in this project was rather limited. A working model was constructed and tested but the simulator was not exploited its full potential. Based on preliminary results obtained from the simulator, conveyor simulator tests showed the following conclusions can be the same general trend as the model conveyor for the variables considered. For example, the surcharge angle (related to the area ratios) decreases with increased idler spacing and/or belt

speed. However, the effect of moisture condition proved to be insignificant to these tests. In view of the greatly reduced costs of design and construction and the ease of testing, it appears that the conveyor belt simulation has considerable potential as a means for investigating the response of conveyor belt systems even though it may lack some of the versatility of the conveyor system. It is recommended that additional development and testing be done if additional funds become available.

Appendix A

EXPERIMENTAL DESIGN

A tentative fractional factorial design has been developed for conducting the experimental investigation. This program is very flexible and variables can be added or deleted as necessary during the testing program. Regardless of the number of important variables that are finally formed in the testing program, this method of experimental design will optimize the amount of significant data obtained from a given number of experimental runs.

Variables Being Considered

The following list of variables is considered tentative as some may have to be added or deleted as testing progresses. The equipment variables that are being considered, but not limited to, are:

g_1 = belt speed

g_2 = belt inclination

g_3 = change in inclination

g_4 = cross section configuration of conveyor bed

g_5 = belt material (coefficient of friction)

g_6 = idler spacing

g_7 = belt tension

The material variables that are being considered, but again not limited to, are:

q_1 = particle size distribution

q_2 = particle shape

q_3 = angle of internal friction

q_4 = moisture content

The total muck removal rate (V) is a function of the equipment and material variables:

$$V = f(g_1, g_2, g_3, g_4, g_5, g_6, g_7, q_1, q_2, q_3, q_4)$$

Procedure

The general procedure of setting up the factorial and fractional-factorial designs and of computing the results is well known (4). The first step in the experimental design procedure is to choose a high and low value for each test variable (since a two-level factorial and fractional factorial design will be used). It is assumed that any nonlinear relationships will not significantly affect the analysis. These values can be chosen from design manuals, manufacturing manuals, or from experimental models. Careful consideration should be used in selection since a good representative of high and low values will reduce the number of tests to be run.

After initial values have been assumed, the testing procedure, based on factorial or fractional factorial design, can be established. For example, assume seven test variables. A factorial design for seven variables would be $2^7 = 128$ tests. On the other hand, for a fractional factorial design, the number of tests required is $2^{7-4} = 2^3 = 8$. The notation 2^{7-4} indicates that each variable is studied at two levels, seven test variables are being studied, and four "new" variables (which are linear combinations of the original seven variables) have been added.

The advantage of fractional factorial designs over factorial designs is that the same number of tests (8) can be made for seven variables as can be made for the three variables in the factorial design. The data, however, is not pure as in the factorial design and involves interactions between variables. Therefore, the gain, in terms of the number of runs, may be lost in confounding various combinations of the variables with each other. It is a matter of judgment as to what interactions and of what order can reasonably be ignored. Often the resulting data will provide an explanation of the interaction effects; if not, a systematic method for sorting out the interactions is available. Once the results have been evaluated, additional tests can be run to verify the interpretations for accuracy.

Appendix B

PHYSICAL PROPERTY DETERMINATIONS OF EXCAVATED MATERIAL

A sample of approximately 1000 pounds of material was obtained from a tunnel project in Milwaukee, Wisconsin. This sample was excavated by a Jarva machine and had essentially no particles larger than 1-1/2" (38 mm) sieve size with a high percentage passing the number 200 sieve. The particles were generally plate-like. The grain size distribution curve for this material is shown in Fig. A-1. The specific gravity was determined to be 2.81. The material is a dolomitic limestone.

Two samples of 2400 pounds each were obtained from the White Pine Copper Company, White Pine, Michigan. Sample 1, which is a Freda Sandstone has angular particles, but not as distinctly plate-like as the Milwaukee sample. This material was excavated by a Robbins machine and had an approximate maximum particle size of 7" (180 mm). The specific gravity of this material was 2.77.

Sample 2 was a shale material with angular particles much like Sample 1, but upon drying became very weak along the bedding planes. This material has been identified as Nonesuch Shale. It is quite certain that the material was broken down somewhat due to the violent action of sieving. This material was excavated by a Atlas-Copco machine and had a maximum particle size of approximately 7 in. (180 mm). The specific gravity of this material was 2.83.

The materials were moist when obtained from the tunnel, but the moisture content in the as-received condition is not necessarily the natural moisture content of the material as it comes off the working face since the environment of the tunnel is quite damp. Furthermore, water is sometimes added to the bulk material to reduce dusting at the face. Therefore, no attempt was made to preserve or measure the moisture content of the sample in the as-received condition.

After air-drying, portions of the samples were sized on a Gilson shaker over a size range from 1-1/2 inches down to 200 mesh. The minus 200 mesh material was sized by the hydrometer method in the case of the Milwaukee

material, however the White Pine samples did not have an appreciable amount of minus 200.

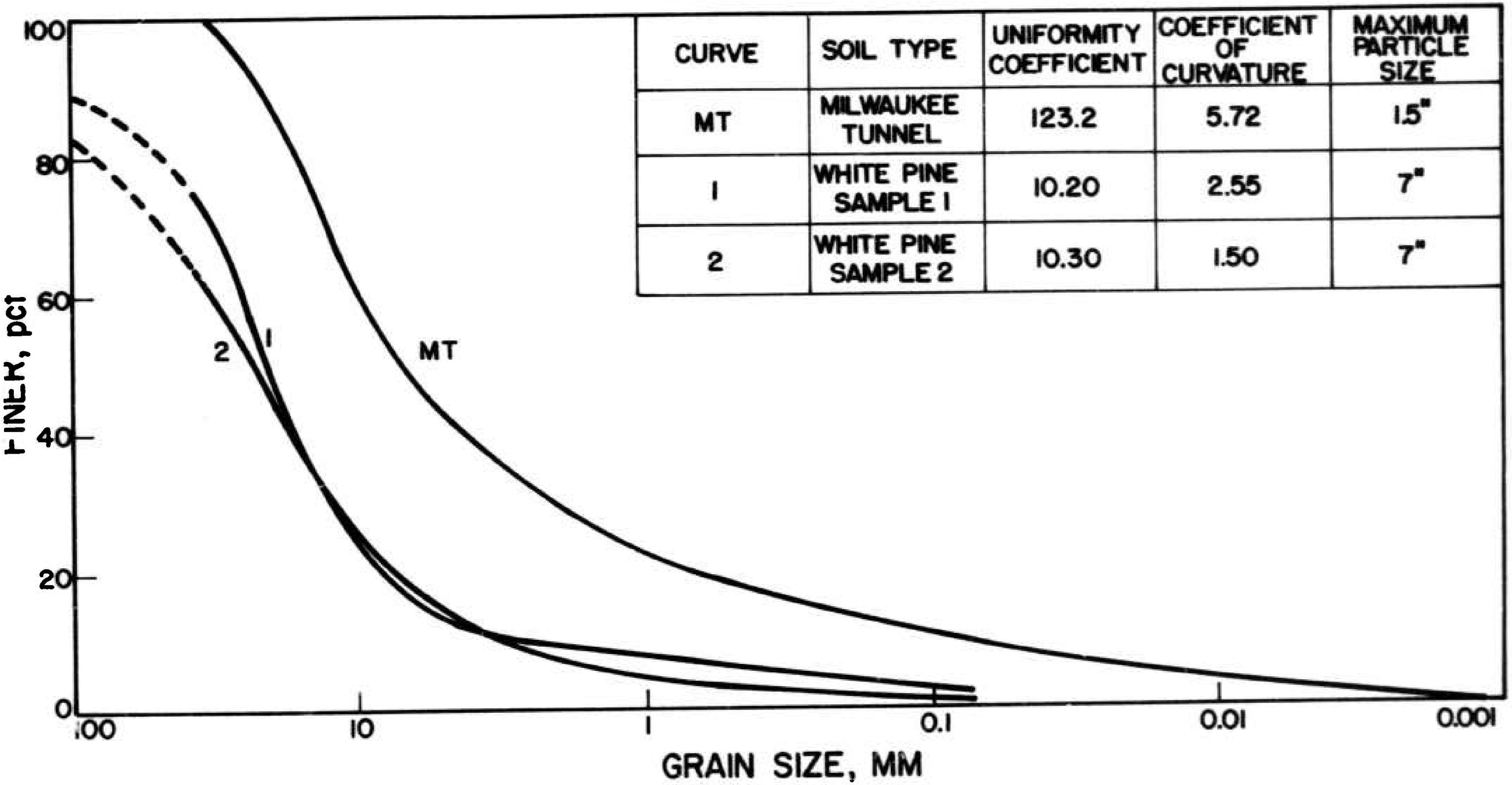
The specific gravity was determined in accordance with ASTM Designation D854-58(1). The rest of the tests were run on minus 4 mesh material. Samples used in the tests were blended in proportion to the size analysis. The minimum bulk density was determined by spooning the material into a 1/30 cubic foot mold. The maximum bulk density in this test was achieved by compacting seven layers with 50 blows each on the Proctor machine. Vibration equipment was unavailable at the time of the test, and some destruction of larger grains was noted due to the compacting procedure. Because of this, maximum bulk density was not run on all samples.

Three direct shear tests were run using different normal stresses on each run. Figure B-2 is a plot showing the results of these tests. The machine was under stress control and the sample was in an air-dried state.

Only tests directly related to material handling were run on the White Pine samples. The results of the tests are shown in Table B-1.

Table B-1 - Physical Properties

	Milwaukee Tunnel Material Dolomite Limestone	White Pine-Sample No.1 Freda Sandstone	White Pine-Sample No.2 Nonesuch Shale
Excavating Unit	Jarva	Robbins	Atlas - Copco
Size of Sample	1000 lbs.	2400 lbs.	2400 lbs.
Approximate Maximum Particle Size	1-1/2 inches	7 inches	7 inches
Specific Gravity	2.81	2.77	2.83
Hygroscopic Moisture Content	0.5	--	--
Angle of Internal Friction	53°(=115 pcf)	--	--
Angle of Repose	45°	44°	45°
Bulk Density Maximum	140.7	--	--
Minimum	95.7	--	--



CURVE	SOIL TYPE	UNIFORMITY COEFFICIENT	COEFFICIENT OF CURVATURE	MAXIMUM PARTICLE SIZE
MT	MILWAUKEE TUNNEL	123.2	5.72	1.5"
1	WHITE PINE SAMPLE 1	10.20	2.55	7"
2	WHITE PINE SAMPLE 2	10.30	1.50	7"

Figure B-1 Grain size distribution

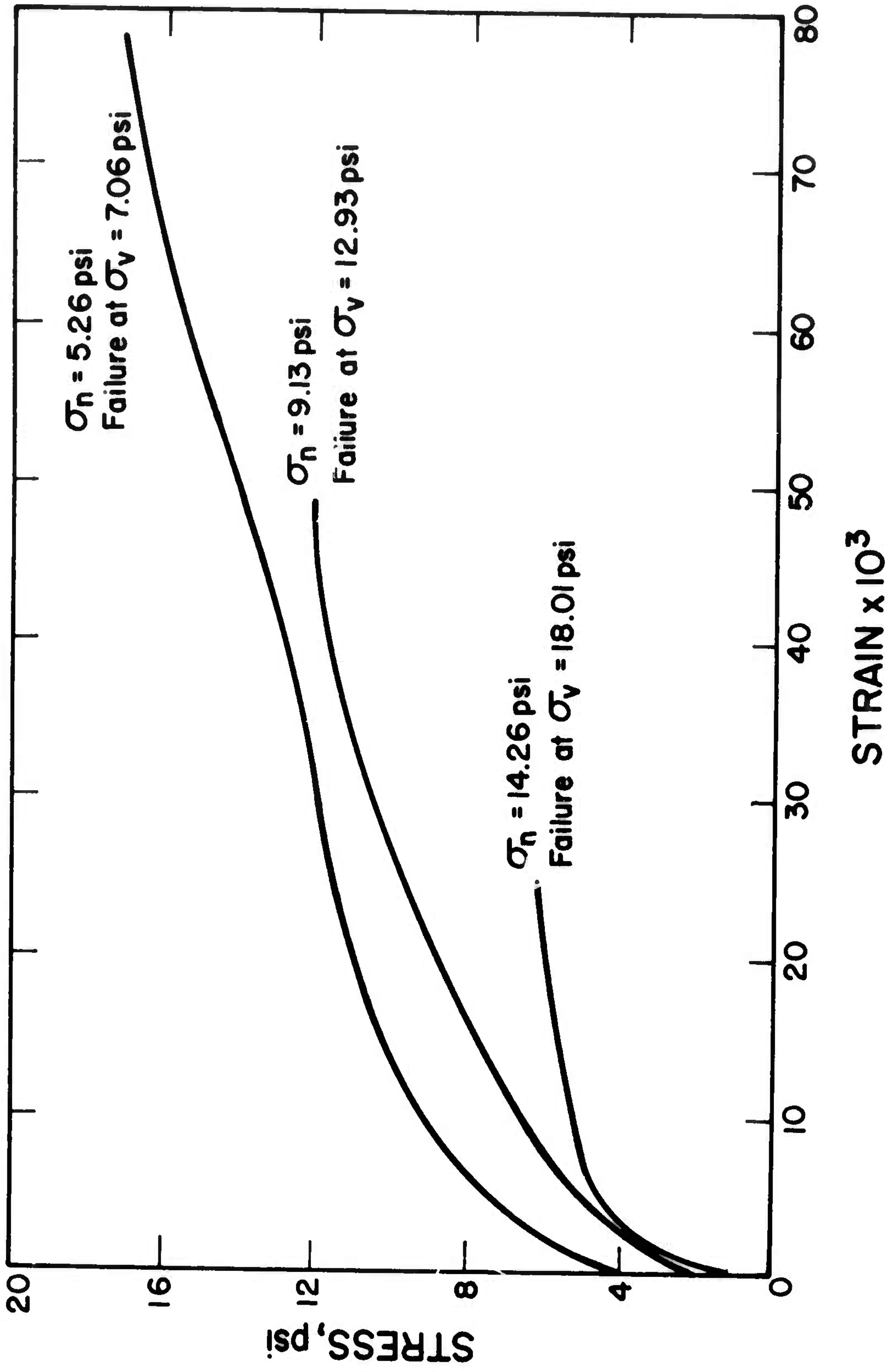


Figure B-2 Stress as a Function of Strain during Shear Test of Milwaukee Tunnel Material